(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) Publication number: 0 320 553
A1

(12) **EUROPEAN PATENT APPLICATION**

(21) Application number: 87311217.1

(51) Int. Cl.4: H01Q 3/26

(22) Date of filing: 18.12.87

(43) Date of publication of application:
21.06.89 Bulletin 89/25

(84) Designated Contracting States:
BE DE FR IT NL SE

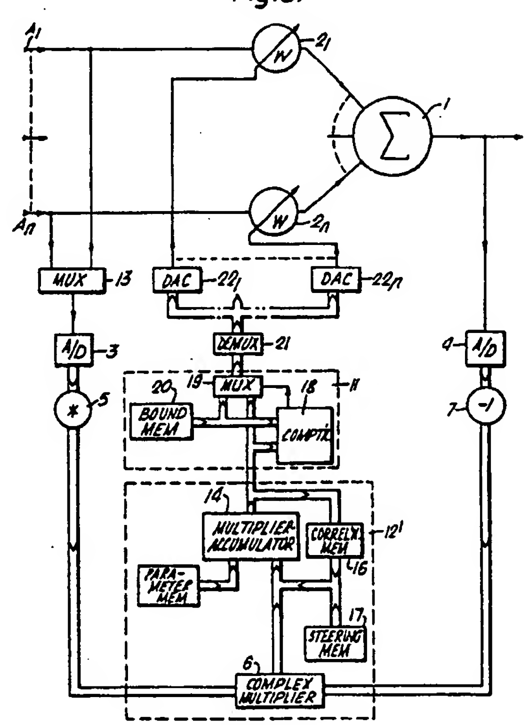
(71) Applicant: STC PLC
10, Maltravers Street
London, WC2R 3HA(GB)

(72) Inventor: Malcolm, Andrew Jonathan Fellows
99, Moor Tower Waterhouse Moor
Harlow Essex CM1 6BE(GB)

(54) **Adaptive antenna systems.**

(57) In the or each steered adaptive control processor loop with weight update gain of an adaptive antenna system is included a weight limiting network (11), which serves to put variable, but equal, bounding limits to each individual inphase and quadrature component of each adaptive weight, whereby to limit the growth of output noise in the presence of a misaligned signal whilst maintaining sidelobe jammer suppression capability.

Fig.5.



EP 0 320 553 A1

ADAPTIVE ANTENNA SYSTEMS

This invention relates to antenna systems and in particular to steered adaptive antenna systems.

The beam pattern of an antenna array is determined by the type of elements in the array, their orientations and position in space and the amplitude and phase of the currents induced in the elements. An adaptive antenna array modifies the pattern in accordance with some control criteria whereby, for example, to steer the beam. An adaptive processor can act to apply complex weightings to the amplitudes and phases of the signals from the elements of the array to provide such adaptive control.

In many radio communications systems the optimum reception of desired signals may be adversely affected by the presence of one or more unwanted interference or jamming signals. By employing an adaptive antenna array for the receiver it is however possible to modify the associated radiation pattern of the array to create a null(s) centred on the direction of the incoming jamming signal(s).

In a number of communications systems the position of the transmitter, or angle of arrival, of a wanted signal is known to a moderate degree of accuracy, such that the signal can be put very nearly at the peak of the beam of a beam steering antenna. However, in the presence of high level jamming, even in the sidelobes of the antenna pattern, the signal to noise plus interference ratio (SNIR) falls and the system fails. If the angle of arrival of the wanted signal is known to a very high degree of accuracy, then a steered beam implementation of the Wiener-Hopf solution:

$\underline{W}_{opt} = \underline{R}^{-1}\underline{S}^{*}$ where

$\overline{W}_{opt}$ = Optimal Weight Set;

$\overline{R}$ = the total covariance Matrix including the signal, interference and noise;

$\underline{S}$ = Space Vector corresponding to the complex envelope of the desired signal received across the array aperture;

may be employed. Alternatively, if some unique signal trait is know, a reference signal may be generated and the optimal weight set thereby obtained. However, with only moderate signal direction accuracy, slight misalignment between the "look" direction and the signal angle of arrival is inevitable. With such a misalignment the "optimal" weight set as defined by the Wiener-Hopf equation (1) steers an antenna null towards the signal, resulting in severe degradation of the output signal to noise ratio.

A system which is capable of broad acceptance to main lobe signals, whilst retaining the ability to steer nulls towards jamming signals arriving via the side lobes, is thus desirable for various applications.

According to one aspect of the present invention there is provided an adaptive antenna system including a plurality of antenna elements and adaptive processor means for processing signals from the antenna elements whereby to steer an adaptive beam pattern, which adaptive processor means applies adaptive complex weights to the amplitudes and phases of the signals from the antenna elements, which adaptive complex weights have inphase and quadrature components, and wherein the adaptive processor means includes means for applying variable, but equal, bounding limits to each individual inphase and quadrature component of each adaptive complex weight.

According the another aspect of the present invention there is provided an adaptive antenna system including a plurality of antenna elements and a respective beam-steering adaptive control processor loop associated with each antenna element, each said processor loop applying adaptive complex weights to the amplitude and phase of a signal from the respective antenna element and generating updated adaptive complex weights for application to the respective antenna element signal in a subsequent cycle of said processor loop, which adaptive complex weights have inphase and quadrature components, and wherein each of which loops includes means for applying variable, but equal, bounding limits to the magnitude of each individual inphase and quadrature component of each adaptive complex weight whereby to limit the growth of output noise in the presence of a misaligned signal whilst maintaining sidelobe jammer suppression capability.

Embodiments of the invention will now be described with reference to the accompanying drawings, in which:

Fig. 1 shows plots of output signal to noise ratio for a single misaligned -10dB source for three processor configurations and various misalignments between processor look direction and signal angle of arrival;

Fig. 2 shows plots of weight norm of the Wiener-Hopf weight set for two -10dB sources, one fixed and the other swept through the main lobe, for various fixed source positions and artificial noise levels, and various misalignments;

(* denotes complex conjugate)

Fig. 3 shows a conceptual processor loop;

Fig. 4 illustrates the employed I,Q bounding in the complex plane, and

Fig. 5 shows a digital processor configuration.

Referring to Fig. 1, which by way of example, shows the output signal to noise ratio for a single misaligned -10dB source for various processor configurations and misalignments between the processor look direction and the signal angle of arrival, with a thermal noise level at -50dB, the array natural beam width being approximately 21°

Curve (a) of Fig. 1 corresponds to the known optimum weight solution as defined by the Wiener-Hopf equation (1) with "artifical" noise added at a level of -40dB and clearly shows inadequate output signal to noise ratio for misalignments of 1/8° or more.

Conversely, the conventional beamformer (curve (b)) maintains gain towards the signal, with adequate signal to noise ratio to beyond 16° misalignment, but with no ability to place nulls against other, unwanted, sources. Curve (c) represents the performance of the weight bounding processor of the present invention which, while 10dB lower than the conventional beam former, retains the important ability to null unwanted signals.

The process of nulling a slightly misaligned signal by a Wiener-Hopf type processor involves considerable weight norm growth, where weight norm is defined as $Nw = \overline{W^H W}^{1/2}$ By way of example, Fig. 2 shows the weight norm growth of the Wiener-Hopf weight set for two -10dB sources, one fixed, the other swept through the mainlobe, for various fixed source positions and artificial noise levels, with thermal noise at -50dB . Curve (a) corresponds to the fixed source located at 35°, well into the sidelobes, with artificial noise at -40dB, and shows a rapid increase in weight norm away from perfect alignment. However, as long as the misalignment is less than approximately 5°, no significant reduction in output signal level occurs. Thus, signal to noise degradation for a misaligned signal is achieved by increasing the weight norm and hence noise output level instead of reducing the signal output level.

Hence, signal to noise ratio improvement may be maintained, even for misaligned signals, by limiting the rise of noise output level, that is, by bounding the weight norm. Bounding the weight norm causes no significant degradation of the sidelobe jammer suppression. Curve (b) of Fig. 2 shows by way of example, the weight norm for a perfectly aligned fixed source with artificial noise added at -40dB. It is apparent that beyond the mainlobe, the weight norm shows no increase over that attained had no swept source been present, confirming that, for a perfectly aligned signal, the processor, even when norm bounded, is able to steer nulls towards sidelobe jammers.

It may be shown (see "Adaptive Array Principles" J.E. Hudson, IEE 1981, pp 175-176) that applying a weight norm bound is equivalent to adding artificial noise to the processor. Thus, by way of example, in order to simulate norm bounding using Wiener-Hopf direct solution method, artificial noise was added at -15dB as shown in curve (c) of Fig. 2. The fixed source is placed with a misalignment of 0.25°. Again the weight norm with the second source in the sidelobes is not significantly above the norm for no swept source present. Hence, provided a sufficient weight norm bound is applied, it is possible to protect a misaligned signal without jeopardising the null steering capability in the sidelobes.

The hardware implementation of a norm-bound system is complex. However, we have found that a similar effect to norm bounding may be obtained by applying a variable, but equal, limit on each individual I (Inphase) and Q (Quadrature) component of each complex weight, thus each weight may occupy a square in the complex plane (Fig. 4).

It is thus proposed to use a weight I, Q bounded processor, which is simple to implement in hardware, to protect misaligned signals whilst also suppressing sidelobe jammers.

The basic structure of the processor loop employed is indicated schematically in Fig. 3. It is based on a conventional steered adaptive control loop using a time-shared digital correlator and serves to "remove" jammers prior to subsequent processing by means (not shown) following summer 1. Each loop includes a weighting network 2 and the outputs of the various weighting networks 2 are applied to summer 1 which is common. Signals from the summer 1 are digitised by ADC (analogue-to-digital converter) 4 and negated by network 7 prior to being passed to digital correlator 12. The signal from antenna element A is digitised by ADC 3 and the complex conjugate of this digital signal determined by network 5 and passed to the digital correlator 12. The correlation result from correlator 12, with the appropriate steering vector added thereto as indicated at adder 10, is passed to a bounding network 11. The network 11 compares the current correlation (weight) with the value contained in a memory and outputs either the weight or the bound, dependent on the result of the comparison. The output is converted back to analogue form and the voltage produced by the digital-to-analogue converter (DAC) controls the weight applied by network 2.

Functionally the digital correlator 12 comprises a multiplier 6, an amplifier 8 and a leaky integrator

9. in series but not necessarily in that order.

Fig. 5 illustrates a more specific digital processor configuration, like reference numerals being used for equivalent elements, which employs a single processor loop. Associated with each antenna element A_1 to A_n is a respective weighting network 2' to 2_n, the outputs of which are applied to the common summer. Signals from the elements A_1 to A_n are selected in turn by an analogue multiplexer 13, digitised by ADC 3, and the complex conjugate of the output of ADC 3 applied to the complex multiplier 6 of the digital correlator which in the processor configuration illustrated in Fig. 5 is combined with the means for adding the steering vector (10-Fig.3) to form a digital correlator and beam steering network 12'. The network 12' consists of five parts: the complex multiplier 6; a multiplier-accumulator 14; a parameter memory 15; a correlation memory 16 and a steering vector memory 17.

The correlation result from network 12' is passed to the bounding network 11 which consists of three parts; a comparater 18; a multiplexer 19 and a bound memory 20. The network 11 compares the current correlation (weight) with the value held in the bound memory 20 and outputs either the weight or the bound, dependent on the result of the comparison. This weight (or bound) is directed to the appropriate DAC, 22, to 22_n, by a demultiplexer 21, the voltage produced by the DAC controlling the weight applied by the appropriate weighting network 2_1 to 2_n.

Claims

1. An adaptive antenna system including a plurality of antenna elements and adaptive processor means for processing signals from the antenna elements whereby to steer an adaptive beam pattern, which adaptive processor means applies adaptive complex weights to the amplitudes and phases of the signals from the antenna elements, which adaptive complex weights have inphase and quadrature components, and wherein the adaptive processor means includes means for applying variable, but equal, bounding limits to each individual inphase and quadrature component of each adaptive complex weight.

2. An adaptive antenna system including a plurality of antenna elements and a respective beam-steering adaptive control processor loop associated with each antenna element, each said processor loop applying adaptive complex weights to the amplitude and phase of a signal from the respective antenna element and generating updated adaptive complex weights for application to the respective antenna element signal in a subsequent cycle of said processor loop, which adaptive complex weights have inphase and quadrature components, and wherein each of which loops includes means for applying variable, but equal, bounding limits to the magnitude of each individual inphase and quadrature component of each adaptive complex weight whereby to limit the growth of output noise in the presence of a misaligned signal whilst maintaining sidelobe jammer suppression capability.

3. An adaptive antenna system as claimed in claim 2, wherein each processor loop includes a weighting network, and wherein the outputs of the weighting networks are summed in a common summer.

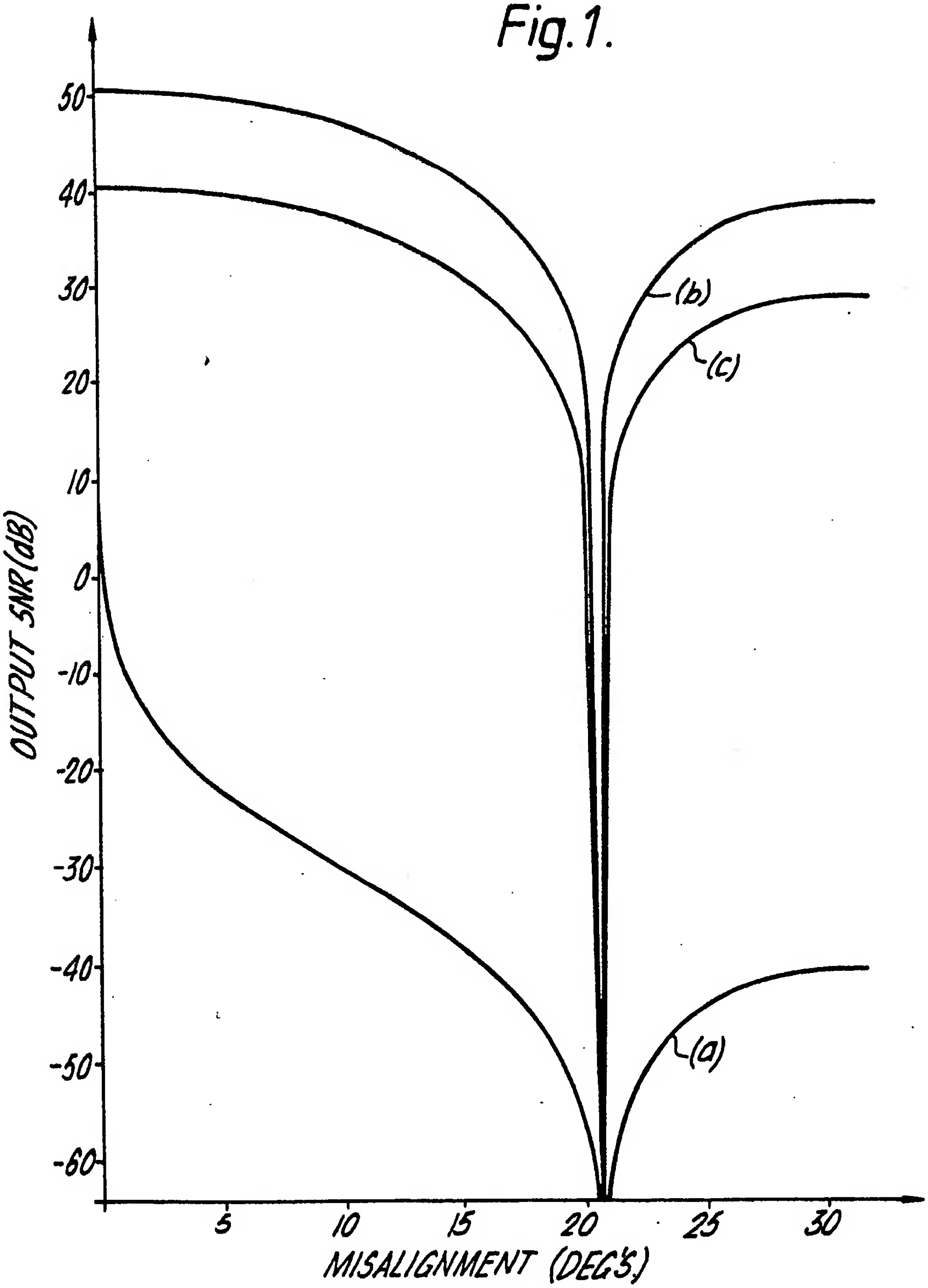
4. An adaptive antenna system as claimed in claim 3, wherein each processor loop includes respective means for correlating a complex conjugate of the respective antenna element output and a negative version of the common summer output, wherein means are provided for adding a respective steering vector to the correlating means output prior to application thereof to said adaptive complex weight bounding means and wherein the output of the adaptive complex weight bounding means is employed to control the weighting network.

5. An adaptive antenna system as claimed in claim 4, wherein the correlating means comprises, functionally, in series, a multiplier, an amplifier and a leaky integrator, not necessarily in that order

6. An adaptive antenna system as claimed in claim 1 wherein the adaptive processor means includes a respective weighting circuit associated with each antenna element, the outputs of which weighting elements are coupled to a common summer, and includes a common beam-steering adaptive control processor loop for each antenna element of the system, which processor loop generates udated adaptive complex weights, and comprises said steering and bounding limit applying means, the signals from said antenna elements being selected by a multiplexer of the loop, and the output of the loop being applied to the corresponding demultiplexer of the loop.

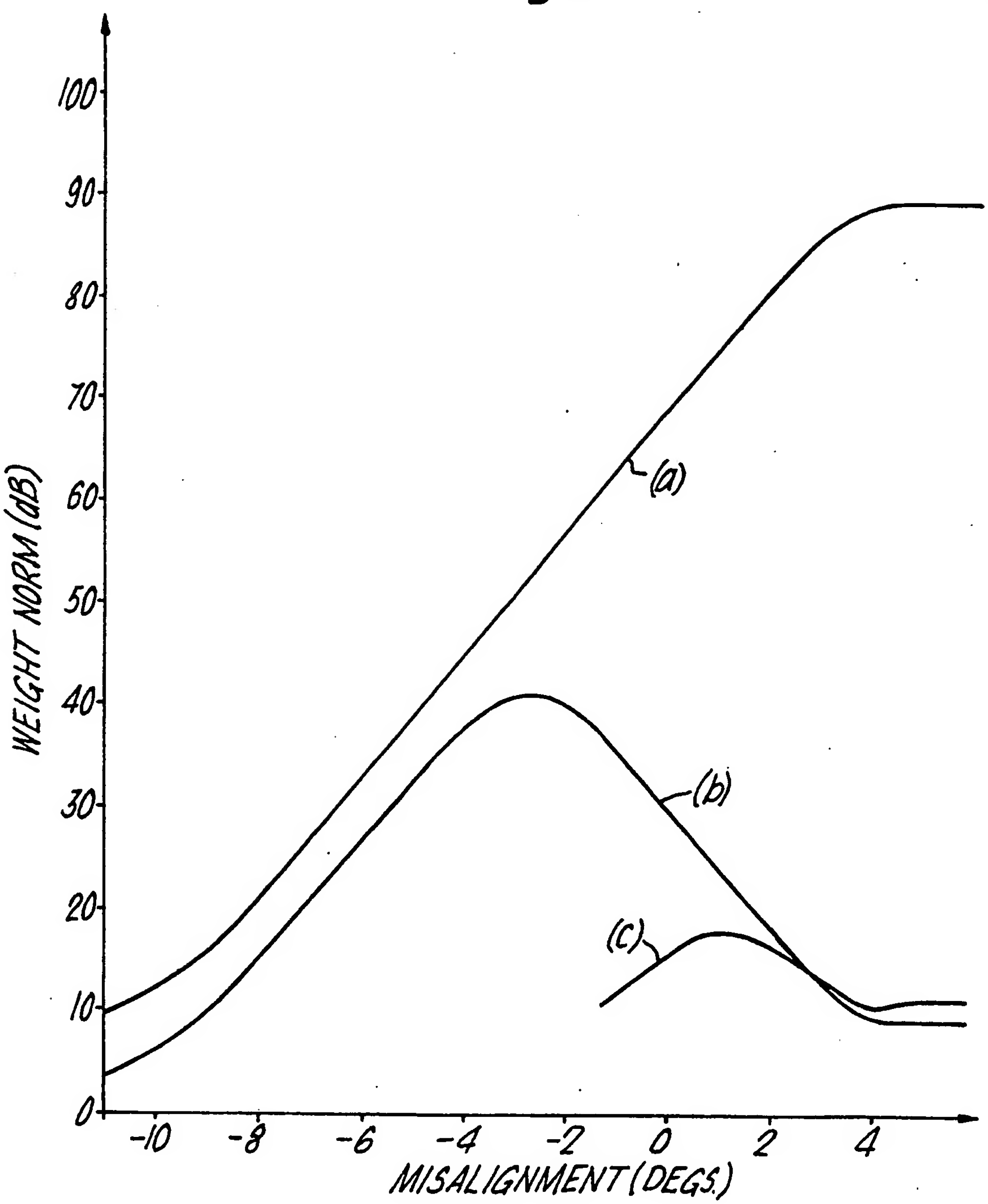
7. An adaptive antenna system as claimed in claim 6 wherein said common processor loop includes means for correlating a complex conjugate of an antenna element signal and a negative version of the common summer output, adding an appropriate steering vector to the correlating means output, and applying the correlating means output with the steering vector added thereto to an adaptive complex weight bounding means, wherein the said bounding limits are applied, before application to the demultiplexer.

Fig.1.



M.A.J. FELLOWS - 1.

Fig. 2.



M.A.J. FELLOWS - 1.

Fig.3.

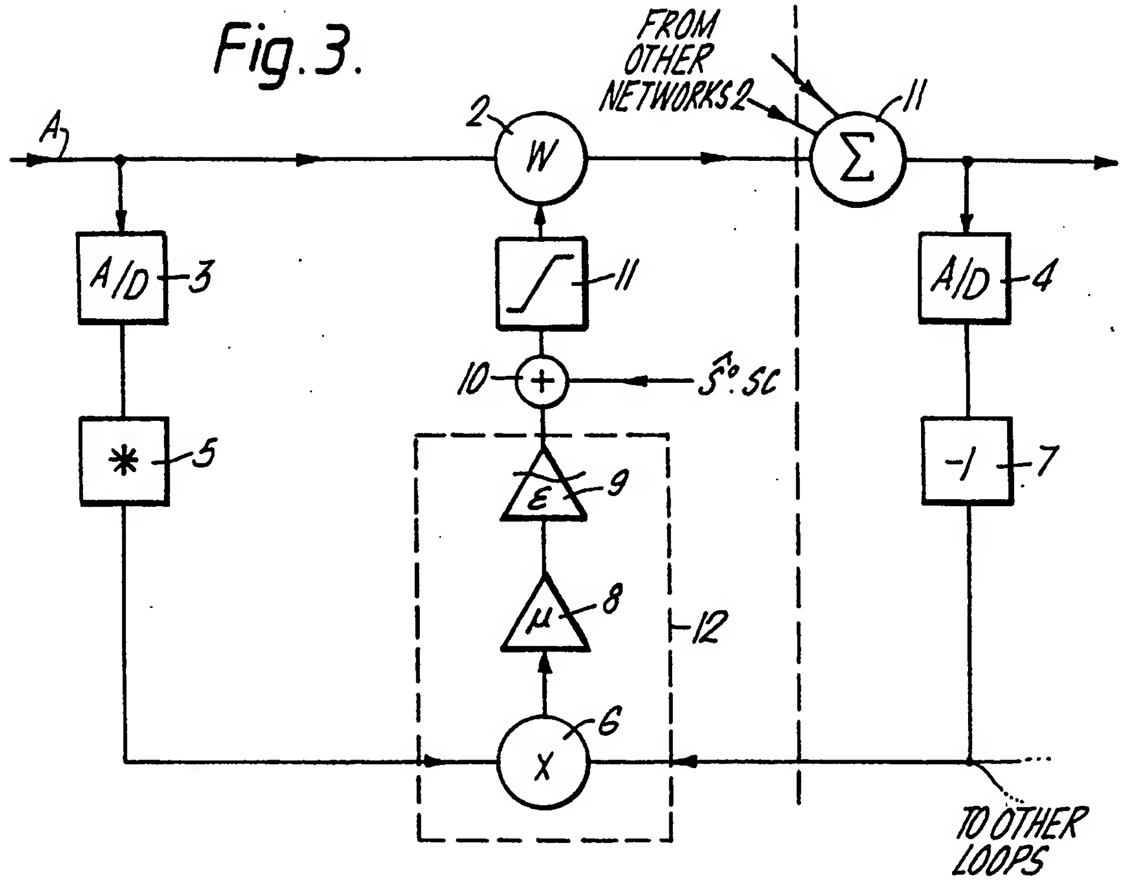
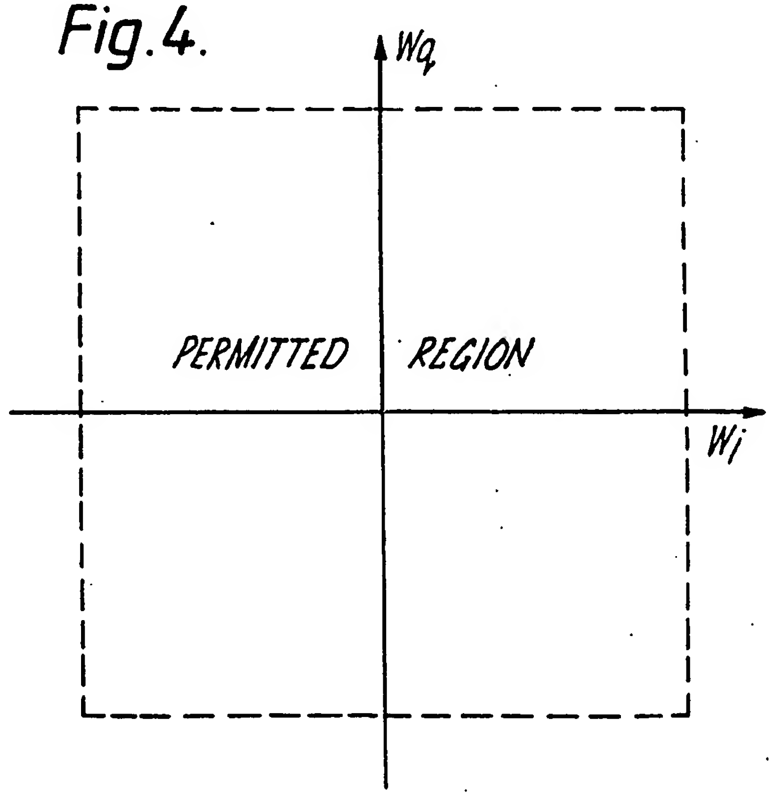
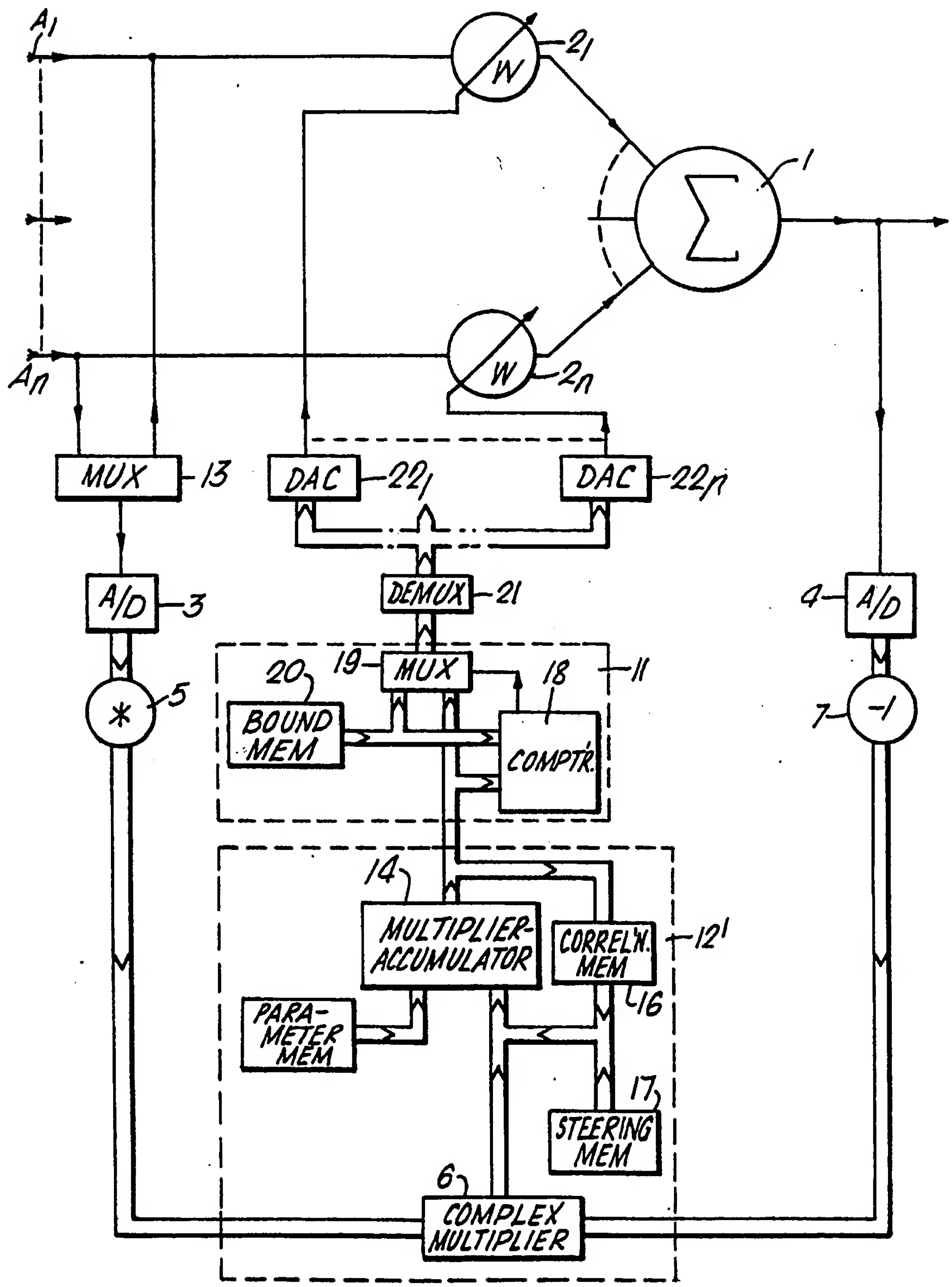


Fig.4.



M.A.J. FELLOWS-1.

Fig. 5.



M.A.J. FELLOWS-1.

European Patent Office

EUROPEAN SEARCH REPORT

Application Number

EP 87 31 1217

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.4)
A	GB-A-2 178 903 (STANDARD TELEPHONE AND CABLES) * figure 1; page 1, lines 8-34 * ---	1,2	H 01 Q 3/26
A	IEEE TRANSACTIONS ON ANTENNAS AND PROPAGATION, vol. AP-34, no. 3, March 1986, pages 330-337, New York, US; N.K. JABLON "Steady state analysis of the generalized sidelobe canceller by adaptive noise cancelling techniques" * page 336, paragraph VII * ---		
A	US-A-4 635 063 (CHANG et al.) * figure 1, abstract * -----		
			TECHNICAL FIELDS SEARCHED (Int. Cl.4)
			H 01 Q 3/26

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
BERLIN	01-07-1988	BREUSING J

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

EPO FORM 1503 03.82 (P0401)